Proceedings of the 12th World Congress on Mechanical, Chemical, and Material Engineering (MCM 2026)
August 18 – 20, 2026 – London, United Kingdom
DOI: 10.11159/htff26.001

Machine Learning Approaches for Predicting Nanofluid Thermophysical Properties

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Extended Abstract

Heat transfer enhancement technologies aim to improve the overall thermal performance of systems, media, and devices involved in heat transport. With the rapid advancement of modern engineering and technology, there is a growing demand for innovative heat transfer systems, advanced coolants, thermal energy storage materials, and efficient heat dissipation strategies. Among these innovations, **nanofluids**—base fluids containing dispersed nanoparticles such as metal oxides, carbides, nitrides, and carbon-based nanomaterials—have attracted considerable attention for their potential to enhance heat transfer performance.

However, accurately predicting the thermophysical behavior of nanofluids remains challenging due to the complex interplay among nanoparticles, base fluids, and suspension stability, coupled with nonlinear effects in heat transfer and fluid flow. Inconsistencies in experimental data, caused by differences in preparation methods, measurement techniques, and nanoparticle dispersion quality, further complicate this task. Experimental characterization is also time-consuming and costly, motivating the exploration of machine learning (ML) as a powerful alternative.

Machine learning algorithms can automatically learn from data, capture nonlinear relationships, and predict outcomes with high accuracy. Various supervised learning techniques—such as multilayer perceptron (MLP), radial basis function networks, and adaptive neuro-fuzzy inference systems (ANFIS)—as well as hybrid models incorporating genetic algorithms (GA), particle swarm optimization (PSO), and imperialist competitive algorithms (ICA) have been explored to improve prediction accuracy and computational efficiency.

In this plenary lecture, I will present recent progress in developing ML-based models for predicting the thermal conductivity, viscosity, and specific heat of nanofluids. Several algorithms, including random forest (RF), extreme gradient boosting (XGBoost), light gradient boosting machine (LightGBM), and stacking ensemble learning, are compared across diverse nanofluid datasets. Cross-validation techniques are employed to optimize hyperparameters and minimize overfitting. The performance of the models is evaluated using mean squared error (MSE) and the coefficient of determination (R^2). Among the models studied, the stacking ensemble approach demonstrates the highest predictive accuracy. These results show that machine learning provides a robust and efficient means to predict the thermophysical properties of nanofluids, offering valuable insights for designing advanced heat transfer fluids and systems.